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Abstract

One of the most critical problems in multihop wireless networks is the fair allocation of bandwidth among different nodes. Although there are significant researches on the fairness issues in single-hop wireless networks, research on multihop fairness rarely found in the literature. A user in multi-hop network, besides the contention with other nodes to obtain the channel in physical layer, must find a solution for the inevitable contention between its own and the relayed traffic in the network layer. Accordingly, a suitable mechanism is needed to schedule data flows in network layer fairly. In this paper, a new algorithm is proposed which tries to allocate node's bandwidth fairly between different contention traffic flows. The main purpose of this algorithm, named HBPQ (History Based Priority Queuing) is the prevention of starvation occurrence for any active flow in the network. HBPQ uses a satisfaction function to measure the user's gratifications and tries to bring close the satisfaction of users. If HBPQ is used for flow scheduling in multihop wireless ad-hoc networks, the simulation results show that each active network's flow, receives a throughput proportional to distance between its source and destination and existing traffic load on its traversed path.

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Fair Data Flows Scheduling Schema for Multihop Wireless Ad Hoc Networks

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Abstract—One of the most critical problems in multihop wireless networks is the fair allocation of bandwidth among different nodes. Although there are significant researches on the fairness issues in single-hop wireless networks, research on multihop fairness rarely found in the literature. A user in multi-hop network, besides the contention with other nodes to obtain the channel in physical layer, must find a solution for the inevitable contention between its own and the relayed traffic in the network layer. Accordingly, a suitable mechanism is needed to schedule data flows in network layer fairly. In this paper, a new algorithm is proposed which tries to allocate node's bandwidth fairly between different contention traffic flows. The main purpose of this algorithm, named HBPQ (History Based Priority Queuing) is the prevention of starvation occurrence for any active flow in the network. HBPQ uses a satisfaction function to measure the user's gratifications and tries to bring close the satisfaction of users. If HBPQ is used for flow scheduling in multihop wireless ad-hoc networks, the simulation results show that each active network's flow, receives a throughput proportional to distance between its source and destination and existing traffic load on its traversed path.

I. INTRODUCTION

When there is no fixed infrastructure such as base station or mobile switching center, users of wireless networks are not able to establish any connection together. Sometimes, although there is a wireless infrastructure, using it is too expensive or accessing to the base station is not easy or the signal strength is too weak. To overcome this problem, wireless clients can establish a wireless Ad-hoc network (WAN). By using of WAN, clients can connect to other nodes in the network without using of any fixed infrastructure[1][2][3].

Because of limitation in transmission range, ad-hoc users usually take advantages of multihop communication. Each node in Multihop Wireless Ad-hoc Network (MWAN) is working as a router to send the packets of other nodes in the network. Each client in MWAN, in addition to send and receive its own traffic, should play the role of switch or router for other nodes in the network[4]. Hence, the usage of priority queuing mechanism in network layer of each node to share existing resources fairly between relayed and its own traffic is inevitable. As shown in Fig.1 there is competition between these two kinds of traffic in network layer to use the shared source. This problem does not exist in wireless local networks or single-hop wireless networks because source and destination are in the communication range of each other.

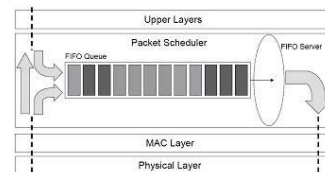


Fig. 1. Standard network layer queue model. Taken from reference[4].

Fairness is an important property of a computer network: when network resources are unable to satisfy demands, they should be divided fairly between the clients of the network. A great deal of research has been done to ensure the fairness of MAC layer[5][6] and the result is that current wireless standards (e.g., IEEE 802.11 [6]) provide quite good MAC layer fairness. Unfortunately, as will be shown in the following, this does not ensure network layer fairness. An appropriate fair scheduling algorithm for network layer in MWANs must have the following properties:

- Building priority queues to serve incoming flows according to their priority.
- Distribute the network layer resources between different flows fairly according to desired fair criterion.
- Fair action in giving services to incoming flows into one priority queue.
- Compatibility with different routing algorithms.
- Increasing overall network throughput.
- Being Stable in high load situation and acceptable total network delay.

Until now, various algorithms have proposed to solve this problem in network layer. Some of the suggested methods try to decrease the network delay[7][8] and in some others, the goal is to increase the total network throughput[8][9]. These methods do not mention the fairness and just try to improve their criteria. In some specific algorithms, authors looking for a mechanism to distribute resources between all the incoming flows in order to guarantee the same throughput for all of them[10]. We believe that fairness is not only the same throughput for all clients, but also the fairness is the same satisfaction for all clients.

In this paper, data flow scheduling in MWSANs is considered and a new algorithm is proposed which tries to allocate

node's bandwidth fairly between different contention traffic flows. The main purpose of this algorithm, named HBPQ (History Based Priority Queuing) is the prevention of starvation occurrence for any active flow in the network. HBPQ uses a satisfaction function to measure the user's gratifications and tries to bring close the satisfaction of users. If HBPQ is used for flow scheduling in multihop wireless ad-hoc networks, the simulation results show that each active network's flow, receives a throughput proportional to distance between its source and destination and existing traffic load on its traversed path.

The rest of the paper is organized as follows: In section II, the satisfaction function is defined and described in details. In section III, some background information are described and through simulation, the unfair treatment received by the multihop flows are shown. The new proposed network layer queue management scheme is explained in Section IV, and provide a comprehensive simulation performance evaluation in Section V. Finally, conclusion of the paper is in Section VI and some open problems and future research directions are highlighted in this section.

II. SATISFACTION FUNCTION

In this section, a Satisfaction Function (SF) for network users in MWAN is defined. Traditionally, fairness is defined as the same throughput for all clients. However, we believe that the same satisfaction for all clients should be considered in fairness definition. For evaluating the end-user satisfaction and obtain numerical result for comparison, a satisfaction function, which can evaluate and show the client's agreements of data transmission in MWAN, is necessary to define. We believe that user's satisfaction means that each user being pleased with data transmission in MWAN according to distance from the destination and the amount of traffic load in the network. For this reason, in SF declaration, the distance between source and distinction of a flow is considered. Certainly, a flow that its source and destination are not far from each other must experience higher throughput in comparison with the flow which its source and destination are far away.

In this paper we have used two parameters, flow throughput and packet's delay. We define the flow throughput as the number of packets which are received from source in destination of flow and measured in destination node. We also define the network's throughput as the sum of flow's throughputs which are active in the network. The packet's delay is the elapsed time from when that packet generated in source node and comes into network layer's queue for transmission until received in final destination node. Flow's delay is the average of its packet's delay and the network's delay is the sum of active flow's delay in the network.

We consider users in the network as traveling data flows and try to bring close their throughput in comparison with their source and destination distance. Based on what mentioned above, SF for flow i in MWAN is defined as following:

$$SF_i = TH_i * (PHN_i + 1) \quad (1)$$

In this equation:

SF_i : Satisfaction Function for flow i .

TH_i : measured Throughput for flow i .

PHN_i : Number of forwarding nodes that exist between source and destination of flow i .

Each time the source and destination nodes are neighbor and in transmission range of each other, there is no need for forwarding node, and based on Equation 1 the Satisfaction of flow i is equal to its throughput. The new algorithm tries to close all flow's SF and guarantee the minimum throughput for all of them. In other word, this method tries to near the satisfaction of network clients which means all users are pleased from data transmission in network.

III. RELATED WORKS

There are just a few works which are previously published on network layer fairness in the literature. Each node in a multihop wireless ad hoc network must transmit its own and underlying traffic. Therefore using a suitable mechanism in network layer of nodes is necessary. The first solution was proposed by Jun[10] to use different queues for relayed and originating traffic to serve them in a round-robin fashion(in the following of this paper this method called Two Queue(TQ)). Isolating the originating traffic by putting two queues at the network layer still shows significant unfairness of the throughput. Although this scheme is simple to implement and prevents the severe starvation due to the relayed traffic but, fairness is guaranteed only when the length of a data flow chain does not exceed two hops. To alleviate the unfairness problem of TQ, Jun[10] assigned different weights to each queue. By this means, relayed traffic queue will receive more bandwidth when it is required. In current paper, this method is called Weighted Two Queue (WTQ). The weight of the forwarding queue can be fixed in all the nodes of the network or different weights can be used, depending on the amount of relayed traffic at each node. The latter assumes that the amount of relayed traffic can somehow be determined in a distributed manner. By simulation will be shown that WTQ acts better in providing the same throughput for data flows in the network than TQ. On the other hand, TQ acts much better in providing the same satisfaction for clients.

A more general approach is to use per-flow queuing. This method in this paper is named as Round Robin (RR)[10]. Packets of different flows are enqueued separately (based on their network-layer source address). Although this method can fairly distribute the network layer resources between data flows, as will be shown later, RR acts poorly in providing the same SF for network's clients. On the other hand, by use of this method, there may be lack of network layer resources to do per-flow queuing (e.g. in a large sensor network).

Some other solutions tried to solve network layer scheduling problem by isolating the data and control traffic in network layer. In one of these algorithms[7], the highest priority is given to the control traffic and data traffics queued separately based on their distance to the destination. Each flow which is belonged to the nearer destination, located in higher priority

queue. Authors use two routing algorithms, DSR [11] and GPSR [12] to evaluate the remaining distance between each node and its relayed flow's destination. They try to minimize the network delay but do not mention fair resource distribution and client satisfaction and some time these two problems cause starvation for relayed traffic.

In the year 2005, a solution was presented for network layer scheduling in [8] which was very similar to [7]. In this algorithm data flows queued based on the remaining distance to their destinations and the distance they have traveled from their sources. To evaluate the number of remaining and traveled hops, this method uses DSR routing algorithm. In the current paper, this method is called Weighted Hop Priority (WHP). In WHP, classification in each node is performed dynamically by use of two factors: remaining distance and traveled distance. However, WHP uses two factors to schedule the data flows in network layer, but one of the most important problems of WHP is that this algorithm does not mention the scheduling of data flows in one priority queue and this ignorance may causes starvation for data flows which travel long distance to arrive to their destination. Hence as will be shown in simulation results WHP increases the network throughput and has less network delay in compare with other methods. However the solution can't guarantee the minimum throughput for all users. Another disadvantage of this solution is that it can not distribute the network layer resources fairly.

In this paper, we consider the advantages and disadvantages of previous algorithms to develop a new method of scheduling for the network layer of multihop ad hoc networks. In the next section the details of the new suggested algorithm will be described.

IV. HISTORY BASED PRIORITY QUEUING (HBPQ)

In this section, a new fair scheduling algorithm for MWAN is suggested to provide the same client's satisfactions in network. This method uses SF (which is defined in equation 1) to evaluate the degree of user's agreements. To describe the details of HBPQ operation, the special network model is considered that each network user transmits data for one specific client. Fig.2 shows the flow graph of one MWAN which is consisted of ten users that spread in 500m*500m area. Each node has its own data flow and sends packets to node five.

In this paper, wireless nodes use IEEE 802.11 standard[6] with CSMA/CA[1] MAC protocol in their physical layer. In IEEE 802.11 the maximum transmission distance between two nodes is 300 meter. All users produce the same stochastic traffic pattern. The nodes are supposed to be fixed, because the movement of users and bandwidth lost has almost no effect on data flow scheduling in network layer. For better evaluation of the user's throughputs, the length of all data packets is considered to be 1024 byte. Therefore, the number of received packets in final destination of flow for measuring the throughput of each flow is a good criterion. The length of network layer's queue in wireless nodes is fixed and if network

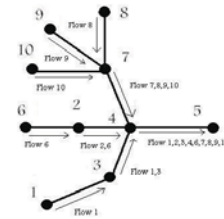


Fig. 2. Data flow graph for a specific WMAN

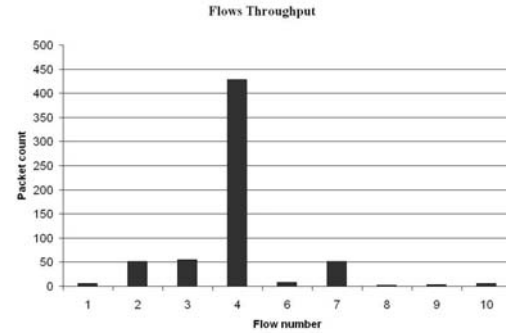


Fig. 3. Evaluation throughput for each flows when standard queue is used

layer queue became full, incoming packets will be discarded. In each node, routing has been performed offline.

In the network of Fig.2, there is nine active data flows, each user has one active flow and all users transmit data to node 5. Except flow 4, all other flows must travel through the other nodes to reach to the destination as depicted in Fig.2. If standard queuing is used in network layer of nodes that packets served in FIFO, when network traffic load is increased and network goes into saturate state (when the node in saturated, the amount of incoming traffic into network layer is much more than leaving traffic), starvation happens for relayed traffic in node 4. When the node's traffic load is increased, network layer queue in node 4 is getting full with its own traffic and relayed packets will be discarded. Fig.3, shows the evaluation throughput in node 5 for each user. The wireless nodes use standard queue in their network layer for data flow scheduling. As shown in Fig.3, some active flows in network are starved and their throughput become zero. Hence the deference between user's satisfactions is high (based on equation 1). To solve the above mentioned problem, two bytes "delay field" is considered in each packet. When a data flow's packet served from network layer's queue, quantity of ϵ is added to "delay field" of other data flow's packets in the queue. Then, between existing packets in the queue, the packet that has the higher quantity in its "delay field" is selected to serve as a next packet. When a packet is generated, its "delay field" is set to zero and each incoming packet is placed in queue based on its experience delay in its "delay field". If the queue is getting full, new incoming packets

are discarded. This new data flow scheduling method named History Based Priority queuing (HBPQ). This process causes that each data packet receives services from the queue based on its experienced traffic load in traveled path. The highest experienced traffic load in traveled path, the highest priority in the queue.

Indeed in HBPQ algorithm, when a packet from one flow is sent, it gives higher priority to other data flow's packets and causes to guarantee the minimum throughput for existing active data flow in queue. Each packet that has a higher quantity in its "delay field" means that this packet have been waiting longer time than other existing packets in queue and has higher priority to get service. Fig.4 shows the HBPQ algorithm in detail based on pseudo-code.

```

When a packet p arrives:
If (queue!=full)
    packet_access(p,history_delay)
    packet_access(p,source_address)
    Priority_set(p,history_delay)
    If (flow_flag(source_address)==0)
        flow_flag(source_address)=1
        flow_numbers++
    End if
    queue_insert(p, priority_base)
End if
Else
    Packet_destroy(p)
End else

When a packet p departed:
If (queue!=empty)
    queue_remove(p,Head_position)
    if (flow_numbers>1)
        packet_access(p,source_address)
        packet_numbers=queue_length(queue)
        for (i=0,i<packet_numbers,i++)
            queue_access(p1,i)
            packet_access(p1,source_address1)
            if (source_address1!=source_address)
                packet_access(p1,history_delay1)
                history_delay1+=epsilon
                packet_set(p1,history_delay1)
                Priority_set(p1,history_delay1)
            end if
        end for
        sort_queue(network layer's queue)
    end if
end if

```

Fig. 4. HBPQ algorithm

In HBPQ algorithm, when the new packet arrives in network layer, its priority is equaled to its experienced delay. Then it is placed in the queue based on its priority (the higher the priority, the nearer place from the head of queue). When a flow's packet is departed from queue, all the packets in the queue must be checked to determine the packets of other flows in queue and adding ϵ to their "delay field". Then all packets in queue sorted in descending form based on the quantity of their "delay field". Hence, packet that has higher delay, located in the head of queue and selected for

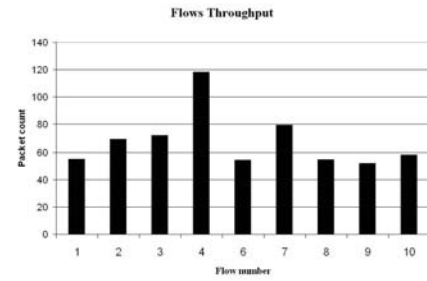


Fig. 5. Evaluation throughput for each flow while HBPQ algorithm is used

next departure.

HBPQ algorithm uses "delay field" to save the amount of traffic load that each packet experiences on its path. During the simulation, this field is considered as 2-byte unsigned integer space. This number set zero when the packet is generated. If the quantity of ϵ which is added to "delay field" is set to 1, the "delay field" can count 65535 packets of each data flow. Certainly when the number of existing data flows in network is getting high, the space of "delay field" can be considered as a 4 byte decimal number and set the value of ϵ to a very small value (near to 0.1). This is essential to remember that if the length of transmitted data packet in network is less than 64 byte, embedded 4 byte into each packet for scheduling is not reasonable and causes to waste useful network bandwidth.

In the remaining parts of this paper it will be shown that the proposed mechanism, in addition to guarantee the minimum of throughput for active data flows in network and prevention of starvation, can nearer the satisfaction of WMAN's users in comparison with other network layer scheduling methods. As a matter of fact, by means of this algorithm, network users are pleased from data transferring in WMAN, based on distance to their destination and existing traffic in the path.

To assess the HBPQ scheduling method and compare its operation with traditional scheduling model, again consider the network which is shown in Fig.2. Fig.5 presents the evaluation throughput for each data flow when nodes use HBPQ algorithm in their network layer for data flow scheduling. As it is revealed, in comparison with Fig.3, none of data flows in network became starved. Fig.6 shows the satisfaction of network users when two data flows scheduling algorithm (SQ and HBPQ) is used in network Fig.2. It is clear that HBPQ algorithm can nearer the satisfaction of network client in compare with SQ method.

V. SIMULATION

In this section, the operation of HBPQ data flow scheduling algorithm is compared with other methods. SQ, TQ, WHP, WTQ and RR scheduling methods are considered for comparisons. These methods are introduced in Section II.

Number of data flow's packets that received by the destination and the average of delay that packets of one flow

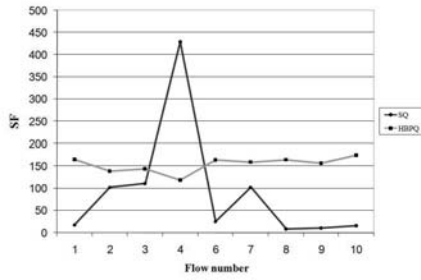


Fig. 6. SF comparison for two data flow scheduling algorithms (SQ and HBPQ)

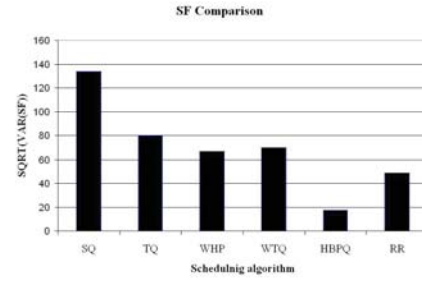


Fig. 7. Measured deviation of standard from users satisfaction function for each data flow scheduling method

experienced on their path, are two criterions which are used for comparison of different algorithms. Due to the use of equal size data packets, the number of received packets by destination is a good standard for evaluation of each data flow's throughput. At the other hand, the average of delay that is measured for each data flow, can be used as an argument to calculate the total network delay. The standard deviation is used to compare different methods in the view of user's satisfactions. Each algorithm that has a minimum standard deviation, works better in providing the same user's satisfactions. This means that by the use of the algorithm with smaller standard deviation, users have smaller difference in their satisfactions.

Simulations are repeated for each method 10 times and the final results are averaged. When the number of nodes in the network is 10, simulation time is considered 5000 seconds and network layer queue length is equaled to 5000 packets. However when we have 30, simulation time is set to 10000 seconds and the length of network layer queue is considered to be 10000 packets.

At first, the MWAN that is shown in Fig.2 is used. This network is formed from 10 nodes and node 5 is the destination of all active data flow. Fig.7 shows the measured deviation of standard from users satisfaction function for each data flow scheduling method. It is obvious from the figure, that HBPQ algorithm operate better than other methods to near the satisfaction of network users together. Although RR method can prepare the same throughput for all active data flows in network but always fairness is not the same throughput. By use of RR, Data flow number 4 that is located nearer to destination than data flow number 10, both of them has the same throughput. This causes the difference between satisfactions of this two users.

Another important criterion that is used to compare data flow scheduling methods with HBPQ algorithm was the average network delay. In this paper, different algorithms based on delay that they impose on network transmission are compared. Fig.8 shows the average network delay for each method. Fig.8 demonstrates that HBPQ algorithm which did better in providing the same user's satisfactions, has less total network delay compared with other methods although this method gives

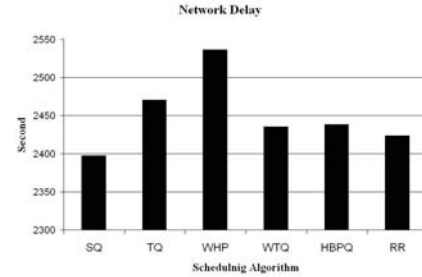


Fig. 8. Average network delay for each data flow scheduling method

much more resources for long path flows to near the client's SF.

In WHP method, because of giving high priority to data flows that travel much more intermediate nodes, this automatically increases the total network delay. It should be mentioned that the purpose of designing WHP is to decrease the total network delay. However, in network of Fig.2 destination of all data flows is the same and WHP method just uses *weighted hop threshold value for incoming packets*. Hence, long distance flows take higher priority in scheduling and this causes increasing the total packet delay. Fig.8 shows that HBPQ has a less total network delay in comparing with other methods. In the following paragraphs another network is considered that nodes send data to different destinations.

For another simulation and comparison scenario, a WMAN with 30 nodes is used which spread in a square with 2000 meter dimension. Clients send data to 5 different destinations. Fig.9 shows the result of standard deviation of user's satisfactions for each data flow scheduling method in this new network with 30 nodes. In this figure, HBPQ algorithm has the minimum quantity of deviation and this means that by use of this method, satisfaction of users are getting closer. Comparison results of different algorithms based on the total network delay is shown in Fig.10. In this figure, WHP has the minimum total network delay because in this scenario both *weighted hop threshold value for incoming packets* and *weighted hop threshold value for outgoing packets* play role in packet scheduling. SO, packets that comes from far sources

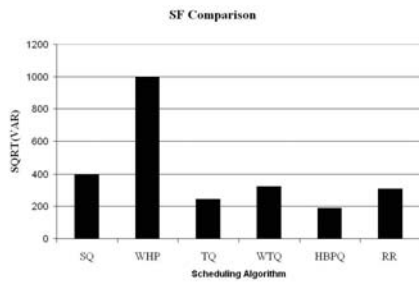


Fig. 9. Measured deviation of standard for each data flow scheduling method in network with 30 nodes

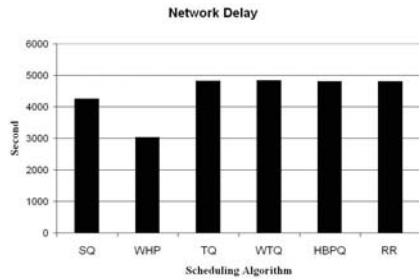


Fig. 10. Average network delay for each data flow scheduling method in network with 30 nodes

and goes to nearer destination, take the higher priority. Except for WHP method, total network delay for other methods is the same.

When the destination of all nodes in WMAN is the same, network throughput for all data flow scheduling algorithms is equal. However when nodes transmit data to different destinations, network throughput and maximum usage of network bandwidth is different for each data flow scheduling. For network throughput calculation, the sum of all active data flow's throughput is used. As shown in Fig.11, WHP method did better in network bandwidth usage. It seems that in WHP, due to the higher priority of packets that are far from their sources and are nearer to their destination, much more packets are received to the destination. Except for WHP method, HBPQ has the best performance between other algorithms. The reason is that HBPQ tries to guarantee the minimum throughput for all active data flows and participates all data flows in network transmission.

VI. CONCLUSION

In this paper, the History Based Priority queuing (HBPQ) method for data flows scheduling in WMAN was suggested. The purpose of this algorithm is to enclose the satisfaction of network users. In WMAN, users that have the nearer destination expect to get higher throughput in compare with others. We believe that in multihop situation, fair sharing of resources between competition flows, does not mean guarantee the same throughput for all of them. Fairness in resource

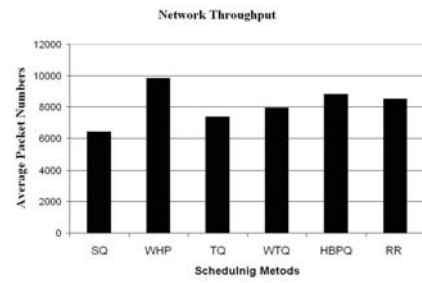


Fig. 11. Network throughput for each data flow scheduling method in network with 30 nodes

sharing between competing data flows is that each data flow based on length of its path and existing traffic on its path, achieve reasonable throughput. At the other hand, HBPQ method prevents data flows from starvation. the reason that HBPQ employs packet's experienced traffic load as packet's weight and this causes that data flows with high load path take higher priority in scheduling. In addition to these properties, HBPQ in compare with other methods has less total network delay. The simulation results showed that HBPQ has the maximum usage of network bandwidth and improves the total network throughput.

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